# TEST OF A POTASSIUM CHLORATE SIGNAL CELL

BY
JOHN S. REID, JR.

ARMOUR INSTITUTE OF TECHNOLOGY

1911

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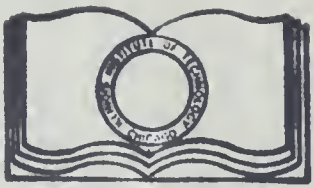
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Test of a potassium chlorate
signal cell

TEST OF A POTASSIUM CHLORATE SIGNAL CELL.

# A THESIS

PRESENTED BY

JOHN S. REID, JR.

TO THE

PRESIDENT AND FACULTY

OF

ARMOUR INSTITUTE OF TECHNOLOGY

FOR THE DEGREE OF

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Calibration of Instruments.

Calibration of Instruments.

## Calibration of Instruments.

The instruments used to measure the current and voltage for these tests were Weston ammeter #110 and Weston Volt-meter #1139., Weston A[illegible]meter #114.

Due to the tendency of electrical instruments to read incorrectly after a time by reason of their construction or because of mechanical injury, it was deemed advisable to calibrate the instruments used by comparing them with a standard instrument known to be correct.

Each instrument was calibrated before and after the tests and an average value taken from the calibration curves in place of the observed readings. These average values were used in plotting curves and making calculations. The original data as read directly from the instruments was not recorded.

The calibration curves using the average values follow:

## Calibration of Ammeter #110.

| Ammeter #110 | Standard Millivoltmeter # with ampere shunt. |
|---|---|
| .0 | .0 |
| .5 | .504 |
| 1.0 | .98 |
| 1.5 | 1.48 |
| 2.0 | 1.96 |
| 2.5 | 2.47 |
| 3.0 | 2.98 |
| 3.5 | 3.47 |
| 4.0 | 3.96 |
| 4.5 | 4.45 |
| 5.0 | 4.95 |
| 5.5 | 5.46 |
| 6.0 | 5.95 |
| 6.5 | 6.45 |
| 7.0 | 6.95 |
| 7.5 | 7.45 |

| | |
|---|---|
| 8.0 | 7.95 |
| 8.5 | 8.46 |
| 9.0 | 8.96 |
| 9.5 | 9.46 |
| 10.0 | 9.98 |

Temperature of Standard Instrument--22°C.

Calibration of Ammeter #114

| Ammeter #114 | Standard Millivoltmeter #28 with ampere shunt |
|---|---|
| 0 | 0 |
| .1 | .104 |
| .2 | .201 |
| .3 | .302 |
| .4 | .402 |
| .5 | .502 |
| .6 | .602 |
| .7 | .702 |
| .8 | .800 |
| .9 | .903 |
| 1.0 | 1.003 |
| 1.1 | 1.103 |
| 1.2 | 1.202 |
| 1.3 | 1.303 |
| 1.4 | 1.404 |
| 1.5 | 1.503 |
| 1.6 | 1.62 |

| | |
|---|---|
| 1.7 | 1.72 |
| 1.8 | 1.82 |
| 1.9 | 1.92 |
| 2.0 | 2.02 |

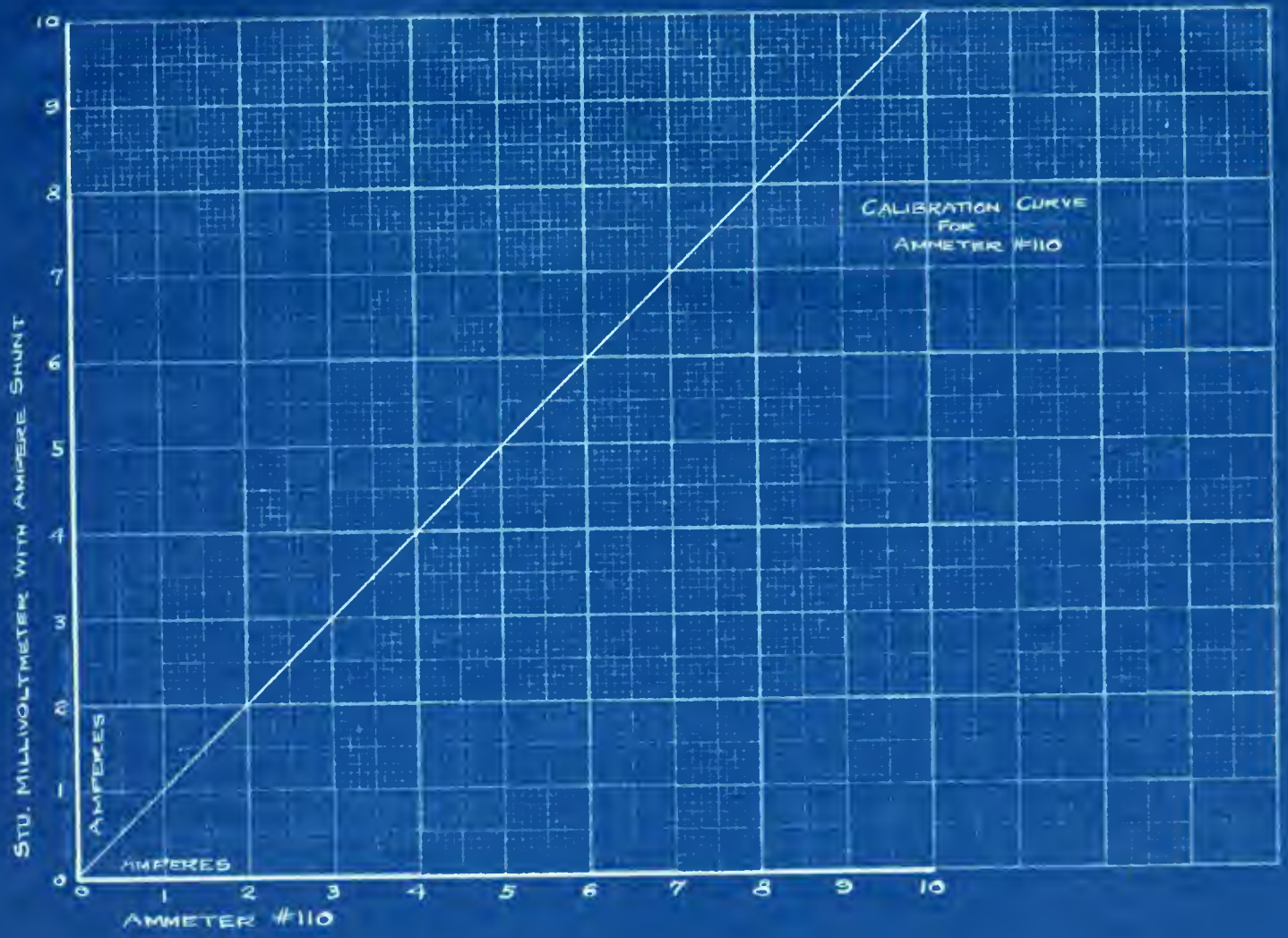
Temperature of Standard Instrument -- 16.6°C

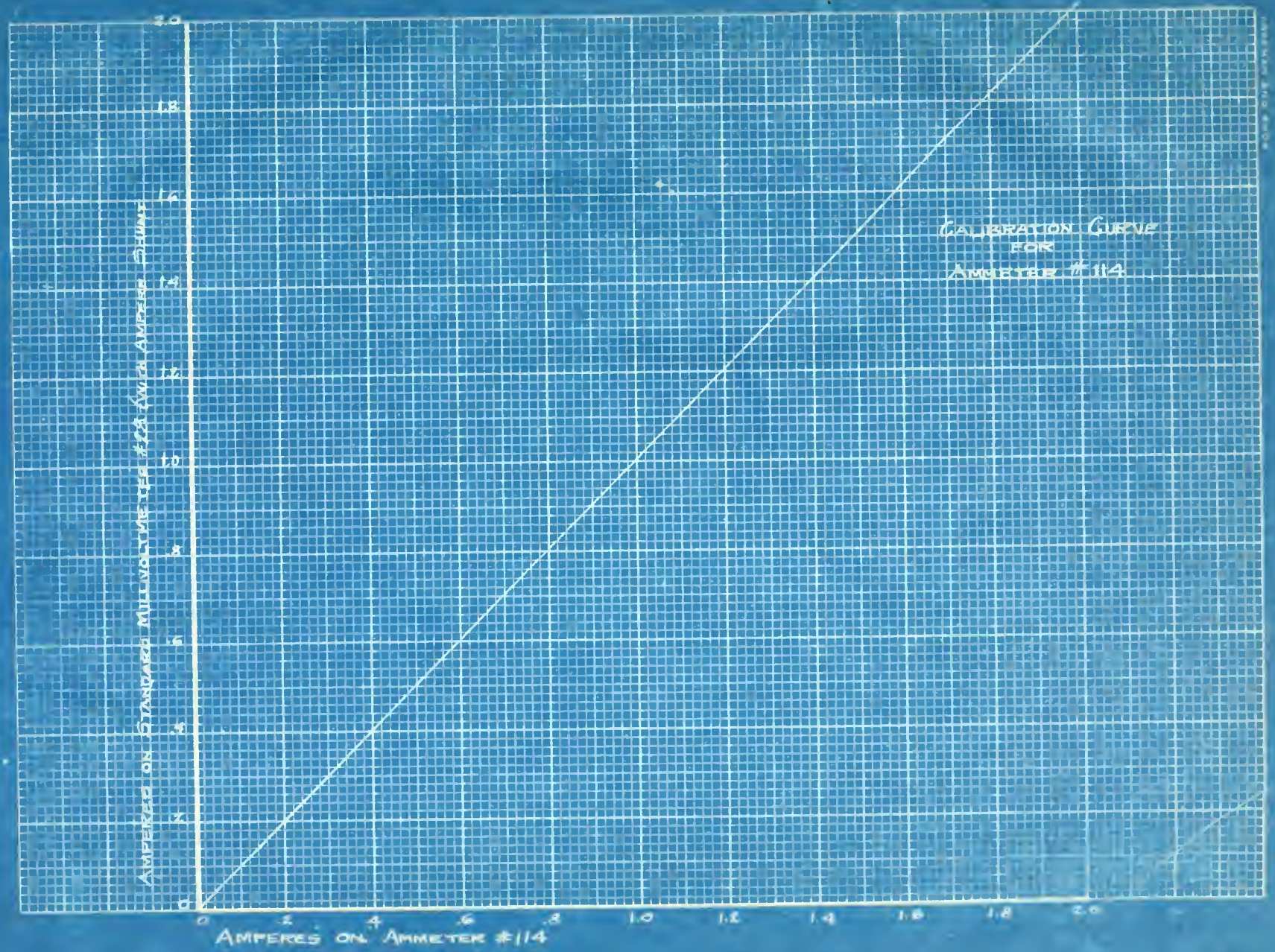
Calibration of Voltmeter #1139.

| Voltmeter #1139 | Standard Millivoltmeter #33 |
|---|---|
| 0 | 0 |
| .22 | .25 |
| .44 | .50 |
| .67 | .75 |
| .89 | 1.00 |
| 1.11 | 1.25 |
| 1.33 | 1.50 |
| 1.55 | 1.75 |
| 1.77 | 2.00 |
| 1.98 | 2.25 |
| 2.21 | 2.50 |
| 2.425 | 2.75 |
| 2.65 | 3.00 |

| | |
|---|---|
| 2.86 | 3.25 |
| 3.075 | 3.50 |
| 3.32 | 3.75 |
| 3.54 | 4.00 |
| 3.76 | 4.25 |
| 3.975 | 4.50 |
| 4.18 | 4.75 |
| 4.415 | 5.00 |

Temperature of Standard Instrument--19.6°C.


CALIBRATION CURVE
FOR
AMMETER #110
STU. MILLIVOLTMETER WITH AMPERE SHUNT
AMPERES
AMPERES
AMMETER #110
0
1
2
3
4
5
6
7
8
9
10


Calibration Curve
for
Ammeter #114
Amperes on Standard Milivolt-meter #24 Amperes Scale
Amperes on Ammeter #114
0
.2
.4
.6
.8
1.0
1.2
1.4
1.6
1.8
2.0

CALIBRATION CURVE
FOR
VOLTMETER #1133
STD. MILLIVOLTMETER #33
VOLTS
VOLTMETER #1133

## INTRODUCTION

It is advantageous and often very valuable to know how a given primary cell will behave when operated under adverse conditions, as for example, when it is required to deliver more current continuously than it is designed to deliver.

It is the purpose of this paper to bring out the more important points in the behaviour of a Potassium Chlorate Signal Cell under such conditions. To this end, two tests were made, one with a large current output and the other with a smaller output.

Two cells were submitted for test. After assembling, one cell was labeled #1, and the other #2 and will hereafter be referred to by number. Before the tests were started, the parts of the cells were carefully weighed. The weights of each part will be found under "Description of the Cell".

Each test will be explained in detail with the accompanying data and curves irrespective of the other test.

A History of the Primary Battery.

As early as 1767 Sulzer announced to the Academy of Science at Berlin the discovery that a peculiar taste is perceived when two different metals are placed together on the tongue and brought into contact at their edges. Such a combination of two metals as copper and silver and the saline saliva forms, as we know, a voltaic couple. But the significante of Sulzer's observation was not appreciated until 1786 when Galvani had made his great discovery that freshly prepared frogs' legs hung by a copper wire over an iron balcony railing, twitched convulsively whenever a portion of the leg touched the iron; and Volta had demonstrated that the effect was not due to animal electricity, but to the two metals; and that electricity, identical with that excited by friction, could be produced by means of the metals without the use of animal tissues, nerves or muscles. Hence arose Volta's contact theory of

electrical excitation which ascribes what is now called the "difference of potential" exhibited by two metals to their mere contact, independently of the medium in which they are immersed.

Volta next constructed a chain of elements to which he gave the name "artificial electric organ" but which has since been known as the "Voltaic Pile". It consisted of many discs of copper and zinc piled up with interposed layers of cloth moistened with acidulated water, the essential condition being that the order zinc, copper, cloth, zinc, copper, cloth be maintained from bottom to top. The bottom disc of zinc was called the negative pole and the top one of copper the positive pole of the pile. A pile composed of from twenty to forty such pairs of plates produced appreciable physiological effects when the experimenter touched the two poles with moistened hands or when the positive and negative terminal wires were placed upon the tongue.

This pile was the immediate forerunner of his "crown of cups", which was the first real voltaic battery - the earliest device to produce a continuous flow of electricity. It consisted of a series of glasses or cups placed in a circle, forming a kind of crown; plates of zinc and copper were so arranged that, being connected at the top the plate of zinc was placed in one cup and the plate of copper in the next.

This battery is truly the model of all those existing to-day and the batteries advocated by Cruikshank, Wolaston, Muncke, Young, Faraday and others were simply more or less ingenious arrangements for joining a large number of cells in a small volume.

The oldest battery of any practical value without a depolarizer is the Smee Battery, invented in 1840, and in which the positive plates are

zinc enclosing between them with proper insulation, a negative plate of thin silver, corrugated and covered with platinum in a very finely divided state. The exciting liquid is sulphuric acid; and the purpose of the roughened surface of the silver is the mechanical dislodgement of the hydrogen as fast as it is released at the negative plate, since it is found that hydrogen is much more easily detached from a rough surface than from a smooth one.

A battery differing from Volta's only in the substitution of carbon electrodes for those of copper was invented by Mr. Walker in 1849. In this cell the negative element is made of gas carbon, which forms in a shell upon the heated retorts in the commercial preparation of gas. This substance has a very good conducting power, and it is very porous. On account of its porosity the electrode presents a very considerable surface which is of service in reducing polarization.

Besides sulphuric acid batteries, hydrochloric acid batteries were constructed but none of the batteries thus obtained were given any continued application, because hydrochloric acid being gaseous and only soluble in water, escapes into the surrounding air so that in a short time it is impossible to remain in the room in which it is placed, the electrolyte becomes impoverished and the current consequently very weak. The same inconveniences are present in the case of batteries made with nitric acid and the latter are more costly.

The first constant current battery was invented by Profesor Daniell of Edinburgh in 1836. The only difference between it and Volta's battery is the addition of copper sulphate around the copper electrode. The nascent hydrogen then decomposes the copper sulphate, the result being the formation of sulphuric acid, a deposition of metallic copper on the copper plate and a practically total elimination of polarization.

Most of the batteries which have been brought out since the Daniell cell are modifications either of its elements or of its liquids or depolarizer. The Gravity Cell, for example, is a modification designed to avoid the use of a porous cup and takes its name from the fact that the zinc and copper sulphates are kept separate by the difference in their densities.

## Theory of the Voltaic Element.

If a thin strip of commercial zinc is immersed in dilute sulphuric acid, a very lively action takes place: the zinc dissolves and a considerable quantity of hydrogen is given off.

But if, instead of the commercial variety, zinc rendered perfectly pure by distillation be employed, the action takes place very slowly and the bubbles of hydrogen remain attached to the plate of zinc and so protect it from further action of the acid.

If a thin plate of copper is now placed in the acid with the zinc, as soon as the two metals touch at one point, the action becomes very vigorous: the zinc dissolves and hydrogen is given off but now from the copper plate and no longer from the zinc plate.

To make as simple a case as possible, suppose that the zinc and copper plates are immersed in dilute hydrochloric acid, every molecule of which

consists of one atom of hydrogen combined with one of chlorine (HCl).

Clausius supposed that in such a liquid a continual interchange takes place between like atoms of different molecules. Thus, the hydrogen atom of any molecule of hydrochloric acid is not permanently attached to the chlorine atom of the same molecule, but is occasionally separated from it and then combines with the free chlorine atom of some other molecule. This interchange goes on indifferently in all directions as long as no outside directive force is introduced.

The hydrogen and chlorine atoms, then, interchange freqently from molecule to molecule at random; and while in the free state between successive pairings, each hydrogen atom carries a charge of positive electricity and each chlorine atom an equal charge of negative electricity.

If we now imagine with Helmholtz that both zinc and copper have an attraction for the

negative charge of the chlorine atoms, the zinc's attraction superior to that of the copper, then it will follow that when the zinc and the copper are immersed in the liquid, an outside force has been introduced among the chlorine atoms, so that their molecular interchanges are constrained to take place in the direction of the zinc. They unite with the zinc, giving up their negative charges until this action is arrested by the repulsion of the negative charge accumulated on the zinc and that of the free chlorine. Only incipient chemical action can therefore take place until electrical connection is made between the charged zinc plate and the copper plate immersed in the liquid with it. Negative electricity then flows toward the copper, through the connecting conductor and unites with the positive charge of the hydrogen atoms which move toward the copper plate to meet the negative current. The hydrogen gas escapes thus at the copper plate; a procession of hydrogen atoms moves steadily in the same direction, either

directly or, with greater probability, by successive molecular interchanges; and the separated electrical charges which quickly accumulate check the movements of disengaged atoms by repulsion of like charges, and all chemical activity ceases.

Thus the condition assumed on open circuit is one of electrostatic equilibrium. The chlorine atoms continue to unite with the zinc and to deliver to the zinc plate their negative charges, until the repulsion between the negative charges of the zinc and the momentarily free chlorine atoms equals the chemical attraction between zinc and the chlorine. The two electrodes will then be oppositely charged and will exhibit a difference of potential.

Any chemical action taking place in a cell on open circuit, tending to reduce its available potential energy, or going on when the circuit is closed and not contributing toward the production of the current, is called local action. Local action is always very noticeable with commercial zinc in zn

acid solution. The zinc contains foreign particles such as bits of iron, carbon, or other bodies of a conducting nature; as soon as these are exposed to the liquid, they form with the zinc closed local circuits, and the zinc is eaten away in patches or pits.

To prevent this wasteful action, the zinc is amalgamated which consists in forming a zinc -mercury alloy on the surface of the zinc plate. This is perhaps best accomplished by first cleaning the zinc by immersing it in dilute sulphuric acid, and then rubbing mercury over the surface.

The action of the amalgam seems to be to bring to the surface pure zinc, while foreign materials, especially iron, are left behind. Amalgamated zinc acts like pure zinc; foreign bodies as soon as they are dislodged fall to the bottom of the cell; and wasteful action due to local currents, is avoided.

The investigations of Reynier show that the protection afforded by mercury is much greater than is generally supposed. In certain liquids the

local waste of amalgamated zinc is fifty, one hundred or even ten thousand times less than that of ordinary zinc.

Reynier further concludes that an alloy of zinc and mercury using four per cent of the latter gives better protection, contributes to the economy of batteries and increases their constancy.

Polarization and Depolarization.

The action which takes place in a cell whose electrolyte is an acid is the decomposition of the acid, the liberation of hydrogen and the formation of a salt of the metal of the anode by its union with the balance of the acid.

This decomposition takes place throughout the space between the anode and the cathode. The hydrogen does not, however, appear throughout the electrolyte but only at the surface of the cathode as mentioned in the discussion of the "Theory of the Voltaic Element".

If at or near the surface of the cathode there is placed some substance with which the free hydrogen may unite, the energy liberated by such formation will add to the E.M.F. of the cell. If this free hydrogen cannot unite with some substance at the cathode, it collects on the surface in bubbles as a gas. In addition to reduction of the E.M.F. of the cell due to the decomposition of the electrolyte, the formation

of hydrogen also acts disadvantageously in that it forms in a layer on the surface of the cathode, which enormously increases the internal resistance of the cell, thus diminishes the current which the E.M.F. of the cell can send through a fixed external resistance. This formation of hydrogen upon the surface of the cathode is known as "Polarization".

The removal of this free hydrogen from the cathode by any means, mechanical or chemical, is called depolarization, the agent used being called the depolarizer. It is removed mechanically by agitating the cathode or by temporarily removing the cathode from the electrolyte when the cell is not in use. The chemical means are by far the most widely used, the effect being to prevent the increase in the internal resistance of the cell.

Batteries may in general be classified as open circuit batteries and closed circuit batt-

eries depending upon the extent to which polarization is prevented. A battery is entitled to be included in the closed circuit class only when it is capable of working on a closed circuit of moderate resistance for a considerable period with but slight diminution in the intensity of the current. It is thus clearly differentiated from those cells that are adapted to stand on open circuit without wasteful local action and to furnish current only at intervals and then of but a few seconds duration.

The cell under test is of the closed circuit type, polarization being eliminated. The chemical means of depolarization is employed in this battery which in fact takes its name from its depolarizer.

The depolarizer used, potassium chlorate, operates according to the equation:

$$3\ KClO_3 + 2H_2SO_4 = KClO_4 + 2HKSO_4 + H_2O + 2ClO_2$$

The last term of the second member, chlorine peroxide, is very unstable and breaks up easily into oxygen and chlorine, the former uniting with the hydrogen liberated at the cathode, forming water,

while the latter is given off as a gas.

## Description of the Cell.

The cell tested is known as the "Potassium Chlorate Signal Cell" and was made by The Battery Company of Milwaukee, Wisconsin.

As its name implies it is of the closed circuit type and is to be used in signal circuits requiring a constant current of not more than two-tenths of an ampere or an intermittent current of not more than ten amperes.

It consists in brief of an outer containing jar of glass for holding the electrolyte, a zinc element with its electrode and a porous cup containing the cell's depolarizer and carbon element with its electrode.

The glass jar is eight and one half inches in diameter at the top. It is twelve and one half inches high, made of

material three-sixteenths of an inch thick and weighs from 6.24 to 6.9 pounds. Its total capacity is 579.08 cubic inches and the volume of a layer of jar one inch thick, that is vertically, is 57.72 cubic inches. The center of its bottom is raised thus forming a deep grove around the raised portion, terminating at one side in a deep pocket.

The zinc element of the cell is in the form of a cleft cylinder nine inches high, about three-sixteenths of an inch thick and weighs, when the cell is first set up, 5.84 pounds. The circumference of the zinc as measured on a plane cutting the cylinder perpendicularly is about 1' - $1\frac{3}{4}$" with a cleft whose average width is $1\frac{7}{8}$".

The zinc electrode is an insulated copper wire extending through a glass tube

which is $\frac{1}{4}$" in diameter and exposed $1\frac{1}{4}$", and terminating in a copper wire 3/8" in diameter covered with water proof insulation. This enlarged portion is $\frac{1}{2}$" in diameter and 10" long.

The porous cup is of unglazed earthenware about 5/32" thick, 4 3/16" in diameter and $10\frac{3}{4}$" high. It contains the carbon element and the depolarizer of the cell. This carbon element consists of a ring of porous carbon $\frac{1}{2}$" thich fitting closely to the inside wall of the cup and extending from the bottom to within approximately one inch of the top. To one point of the carbon ring is attached the carbon electrode by means of a screwed brass connector and mercury contained in a small inverted cup-shaped glass dish, the connector screwing directly into the carbon about one inch.

A similar glass is placed above and in contact with the other , base to base and is held tightly against it by means of the screwed connector. The internal connection of the connector through mercury to the carbon and the connection of the wire leading from the connector to the outside circuit are protected from corrosion by paraffine oil, it in the latter case nearly filling the upper glass cup-shaped dish above referred to. The space in the center of the carbon ring is partly filled by a cylindrical glass tube 10" long, about 1¼" in diameter, which is equipped with small holes quadrantly arranged in a horizontal meridian plane. The remainder of the space inside the ring is filled with granulated carbon.

The cell is set up in the following manner. After washing glass jar,

cup and zinc, the zinc is placed in the groove about the raised center in the glass jar, its ~~its~~ opening coming opposite the deep pocket. The cup is placed on the raised center of the jar and two fluid ounces of mercury poured into the groove thus surrounding the zinc and filling the pocket with mercury. The enlarged copper end of the zinc electrode is then brightened with a file and placed in the pocket of mercury.

Ten ounces of potassuim chlorate are placed in the cup. Two solutions are next placed in the cell-- a solution for the cup and an outer sclution in the glass jar. These solutions are made by mixing chemically pure sulphuric acid, about 1.84 specific gravity, with distilled water until the mixture stands 1.0741 to 1.0902

specific gravity, or 10° to 12° Baume, both solutions having the same density. The cup solution is poured over the potassium chlorate which is submerged but not dissolved while the outer solution is poured directly into the glass jar. Both solutions are adjusted until they stand one half inch below the top edge of the cup.

After setting up for the first time the cell should be allowed to stand on open circuit for one half hour so that it may reach a normal condition. The voltage of the cell on open circuit at a temperature of 70° Farenheit, or 21.1° Centigrade, should be a little over two volts.

The cell is recharged by siphoning off the old solutions and adding new solutions having a density two degrees higher than the original solutions to compensate for water left over from previous charge in the cup.

The siphoning apparatus consists simply of two lengths of rubber tubing connected by a large rubber bulb, the free ends of the tubes to be placed one in the solution to be siphoned and the other in the receptacle into which the solution is to be siphoned. The liquid being above the receptacle, the flow is started by compressing the bulb with the hand, then pinching the tube just below the bulb; upon releasing the pressure on the bulb a portion of the liquid will flow into the bulb and when the tube below the bulb is released, the liquid will blow into the receptacle and will continue to flow until it is all transferred or until air enters the upper tube. If the tube below the bulb is pinched before the bulb is compressed it will be necessary to compress the bulb strongly several times to drive out the air in the bulb

and upper tube; but, as this air has to pass through the solution, and upon issuing from the solution is liable to cause considerable splashing, this method is not desirable. In case the discharge end of the tube is submerged, it will only be necessary to compress the bulb and release it when the solution will start and continue to flow.

Part I.

Test #1.

Two Cells in Series - High Discharge Rate.

FIGURE 1.

A scheme for connecting up the apparatus used in both tests. The scheme is explained under Test #1.

DIAGRAM OF CONNECTIONS
TEST OF
POTASSIUM CHLORATE SIGNAL CELL
V
A
E
V
B
#2
#1
C
F
D
R

Test #1.

The apparatus required for the tests, other than the batteries, consisted of the following:

(1) 0-2 Direct current, direct reading Weston Ammeter.

(2) 0-10 Direct Current, direct reading Weston Ammeter.

(3) 0-5 Direct current, direct reading Weston Voltmeter.

(4) A variable resistance.

(5) 2 Single pole, single throw switches.

(6) 1 Single pole, double throw switch.

(7) 1 Double pole, double throw switch.

The apparatus was connected according to the scheme shown in Figure 1. The batteries are connected in series with a switch, E, an ammeter and a variable resistance, R. Either the 0-10 ammeter, A, or the 0-2 ammeter A' may

be connected in circuit with the batteries according to whether switch E, is thrown to the left or to the right. The variable resistance, R, consists of a length of #16 Brown and Sharpe Gauge German Silver wire whose length in circuit may be varied by means of connectors.

By closing switch C and throwing switch D to the left, leaving switch F open, the voltage of Cell #1 may be read on the voltmeter V; with the same conditions, but throwing D to the right, the voltage of Cell #2 may be read on V; by opening switch C, closing switch F, and throwing D again to the left, V will indicate the voltage over both.

At the beginning of the test, the resistance R was adjusted to give a constant current of 7.46 amperes. The open circuit voltage of cell #1 was 1.60 volts while that of cell #2 was 1.55 volts. The switch E was then closed and the battery run to exhaustion.

Upon first closing the switch, the momentary current was eleven amperes which quickly decreased and became constant at 7.46 amperes. The closed circuit voltage of cell #1 at 7.46 amperes was .37 volts and that of cell #2 was .46 volts. The values of the current and voltage decrease as the cell continues to remain on closed circuit. The data and curves show this variation with respect to time.

On the data sheets "I" is the current in amperes; "$E_c$" is the closed circuit voltage; "$E_o$" is the voltage at the instant after the circuit is opened and "r" the internal resistance of the cell.

The last mentioned quantity, r, is calculated from the known values of the other quantities. Thus:

$$Ir = E_o - E_c, \text{ from which } r = \frac{E_o - E_c}{I}$$

It will be noticed from the data that the internal resistance of cell #1 increased

from .0729 ohm to an average value of .1747 ohm and that of cell #2 from .0776 ohm to an average of .2015 ohm.

Curves for each cell were plotted showing voltage and amperage of each cell as ordinates and time in hours as abscissas. In order to make the curves as accurate as possible, they were plotted point to point except in portions where an average curve was obviously preferable. This is especially the case with the ampere-time curves since the areas of these curves were very carefully measured with a planimeter to give the total ampere hours of the cells.

At each reading, the temperatures of the cells were noted. At any given time, the temperatures of both cells were practically the same. A curve, with cell temperatures as ordinates and time as abscissas, will be found on the voltage-time curve sheet of cell #1.

Knowing the voltage and current per cell, the watts output may be calculated from the formula:

$$W = EI$$

and knowing the total hours the cells were on closed circuit, the total watt-hours per cell may be calculated from the formula:

$$W' = EIt$$

in which, W' equals output in watt-hours and t is total time in hours. The output per cubic foot of space occupied is found by dividing the total output in watt-hours by the space occupied by the cell in cubic feet, measuring from the floor to one-half inch above the upper oil cup. (The one-half inch is to allow for bend of wire from carbon electrode.)

Both the inner and outer solutions in this test had a density of 11.5° Baume.

Calculations and results:

Cell #1

Wt. of Zn. + Hg. before test = 3265.92 grams

Wt. of Zn. + Hg. after test = 2965.18

loss in Zn. = 300.74 grams

Cell #2

Wt. of Zn. + Hg. before test = 3274.99 grams

Wt. of Zn. + Hg. after test = 2924.35

loss in Zn. = 350.64 grams

Cell #1

Area of amp.-hr. curve = 108.25 sq.cm.

1 sq.cm. = .5 x 5 = 2.5 amp.-hrs.

area = $108.25^{\times 1.5}_{\wedge}$ = 270.625 amp.-hrs.

Cell #2

Area of curve = 129.02 sq.cm.

1sq.cm. = .5 x 5 = 2.5 amp.-hrs.

area = 129.02 x 2.5 = 322.55 amp.-hrs.

Calculated loss:

Amp.-hrs. two cells in series = 270.625
Theoretical loss = 270.625 x 3600 x .000336 = 327.46 grams Zn. per cell or 654.92 grams for both cells, in which .000336 is the electro-chemical equivalant of zinc and 3600 is a conversion factor for changing ampere-hours into coulombs, namely amperes per second.
Cell #2 ran 51.925 amp.-hrs. longer than #1, hence 51.925 x 3600 x .000336 = 62.83 grams should be added to the theoretical loss for both cells so that the total loss = 717.75 grams.

The average voltage of cell #1 as taken from the curve is .144 volts and for cell #2, .300 volts, so that the watt-hours output of the former is 38.97 watt-hours and of the latter 96.76 watt-hours; and since the cells weighed 35.38# and 34.94#, respectively, the output per pound of total weight is 1.1 watt-hours and 2.74 watt-hours respectively. The volume of space occupied by each cell

is 0.494 cu. ft. so that the outputs per cu. ft. of space occupied are 78.8 watt-hours and 196.0 watt-hours respectively.

Cost of materials:

Cell #2

Wt. of outer sol. = 12.85 #

Wt. of cup sol. = 1.89 #

total wt. sols. = 14.74 #

Since density of acid = 11.5° Baume = 1.082 sp.gr., wt. of actual acid = $\frac{14.74}{67.468} \times 5.113 =$ 1.11 #, in which 67.468 = wt. of acid + water per cu.ft. of solution of given density and 5.113 = wt. of acid per cu.ft. of sol. of same density. This amount of acid will make 2.409# of commercial acid assuming that commercial acid has a sp.gr. of 1.84. Then at 1 ~~per~~ cent per pound, the acid used costs 2.4 cents.

10 oz. of $KClO_3$ at 9½ cents per pound costs 5.9 cents. Zinc used = .772 # and costs at 8.5 cents per pound 6.56 cents.

Total cost of materials for 76.76 watt-hours is $0.148 at which rate the cost

per K.W.H. is $1.53

per K.W.H. is $1.55

DATA ON TEST #1.

CELL #1.

Started 4/5/11.

| Time | $E_c$ | $E_o$ | I | r |
|---|---|---|---|---|
| 3:30 P.M. | .37 | 1.06 | 7.46 | .1729 |
| 4:00 | .29 | .88 | 6.30 | .0778 |
| 4:30 | .21 | .77 | 5.83 | .0788 |
| 5:30 | .20 | .75 | 5.78 | .0950 |
| 6:30 | .205 | .75 | 5.94 | .0918 |
| 7:30 | .21 | .77 | 6.1 | .0917 |
| 8:30 | .21 | .80 | 6.18 | .0954 |
| 9:30 | .21 | .82 | 6.21 | .0998 |
| 10:30 | .21 | .86 | 6.26 | .1037 |
| 11:30 | .21 | .82 | 6.29 | .0971 |
| 12:30 | .20 | .83 | 6.3 | .1010 |
| 1:30 A.M. | .23 | .83 | 6.29 | .0953 |
| 2:30 | .23 | .83 | 6.28 | .0954 |
| 3:30 | .23 | .83 | 6.17 | .0974 |
| 4:30 | .22 | .82 | 6.03 | .0996 |

| Time | $E_c$ | $E_o$ | I | r |
|---|---|---|---|---|
| 5:30 | .21 | .82 | 5.97 | .1022 |
| 6:30 | .20 | .79 | 5.75 | .1025 |
| 7:30 | .19 | .79 | 5.65 | .1062 |
| 8:30 | .19 | .76 | 5.40 | .1055 |
| 9:30 | .16 | .72 | 5.18 | .1079 |
| 10:30 | .14 | .69 | 5.00 | .1099 |
| 11:30 | .14 | .68 | 4.88 | .1104 |
| 12:30 | .14 | .69 | 4.84 | .1135 |
| 1:30 P.M. | .13 | .69 | 4.82 | .1162 |
| 2:30 | .12 | .66 | 4.74 | .1137 |
| 3:30 | .10 | .68 | 4.67 | .1241 |
| 4:30 | .10 | .66 | 4.60 | .1216 |
| 5:30 | .095 | .68 | 4.55 | .1286 |
| 6:30 | .095 | .67 | 4.55 | .1263 |
| 7:30 P.M. | .09 | .67 | 4.55 | .1273 |
| 8:30 | .10 | .68 | 4.43 | .1308 |
| 9:30 | .09 | .66 | 4.29 | .1328 |
| 10:30 | .095 | .65 | 4.21 | .1351 |

| Time | $E_c$ | $E_o$ | I | r |
|---|---|---|---|---|
| 11:30 | .09 | .65 | 4.15 | .1349 |
| 12:00 | .04 | .64 | 4.08 | .1468 |
| 1:30 A.M. | .05 | .61 | 4.00 | .1400 |
| 2:30 | .04 | .60 | 3.85 | .1454 |
| 3:30 | .035 | .59 | 3.83 | .1450 |
| 4:30 | .03 | .59 | 3.69 | .1517 |
| 5:30 | .02 | .57 | 3.61 | .1522 |
| 6:30 | .01 | .56 | 3.50 | .1570 |
| 7:30 | .0 | .55 | 3.40 | --- |
| ******* | | | | |
| 11:15 A.M. | --- | --- | 8.26 | --- |
| 11:30 | .40 | 1.03 | 4.60 | .1370 |
| 4:30 | .36 | --- | 2.71 | --- |
| ******* | | | | |
| 10:30 A.M. | .27 | .92 | 4.47 | .1452 |
| 11:30 | .35 | .85 | 3.12 | .1601 |
| 12:30 | .21 | .68 | 3.09 | .1520 |
| 1:30 P.M. | .20 | .68 | 2.95 | .1626 |

| Time | $E_c$ | $E_c$ | I | r |
|---|---|---|---|---|
| 2:30 | .20 | .69 | 2.90 | .1688 |
| 4:30 | .205 | .69 | 2.95 | .1644 |
| 6:30 | .205 | .73 | 2.95 | .1780 |
| 8:30 | .195 | .68 | 2.87 | .1688 |
| 10:30 | .19 | .66 | 2.66 | .1765 |
| 12:30 P.M. | .18 | .61 | 2.51 | .1714 |

TEST #1

CELL #2

Started 4-5-11.

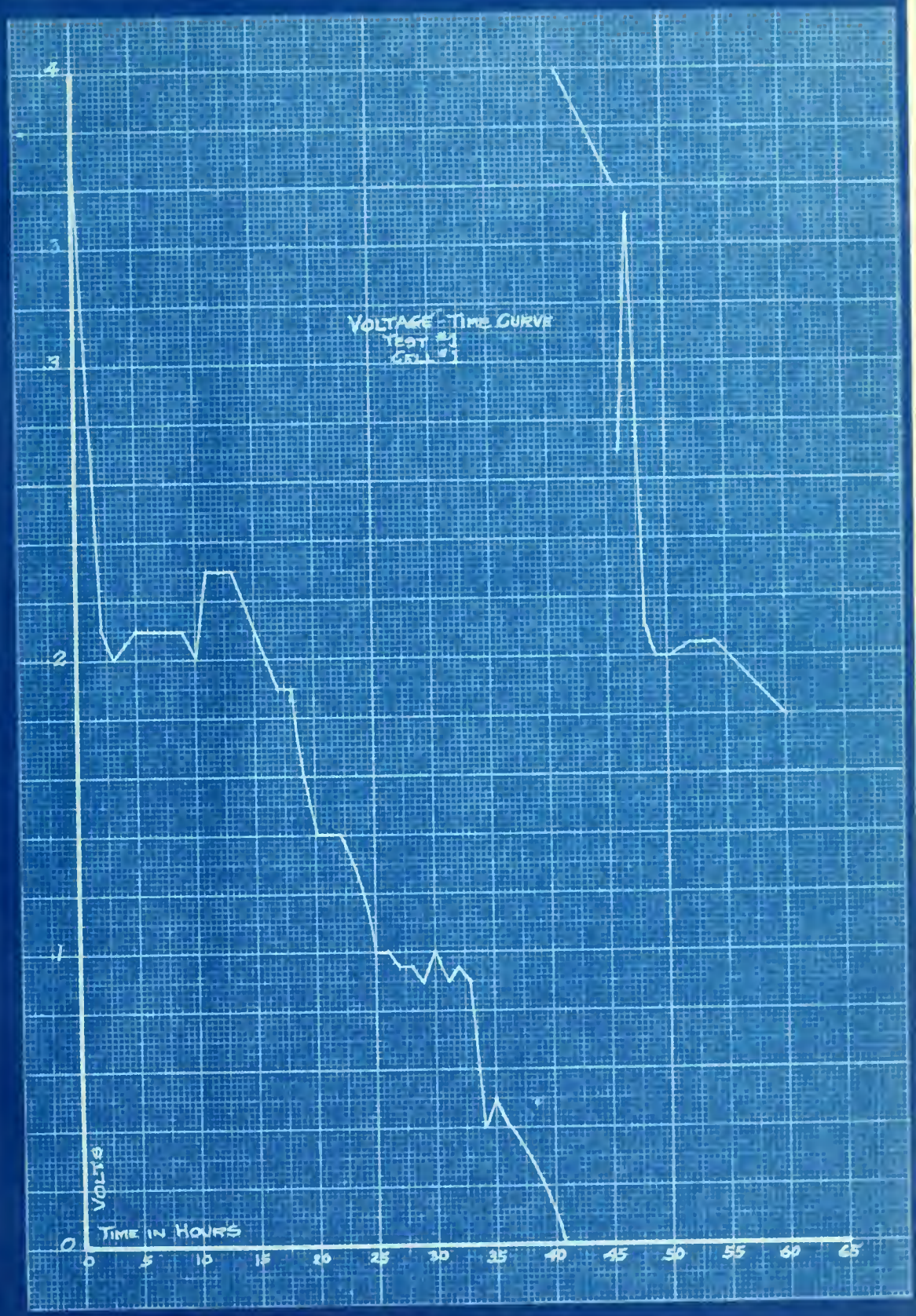
| TIME | $E_c$ | $E_o$ | I | r |
|---|---|---|---|---|
| 3:30 P.M. | .46 | 1.40 | 7.46 | .0778 |
| 4:00 | .39 | .91 | 6.30 | .0826 |
| 4:30 | .42 | .85 | 5.85 | .0748 |
| 5:30 | .43 | .91 | 5.78 | .0830 |
| 6:30 | .44 | .95 | 5.94 | .0858 |
| 7:30 | .46 | .98 | 6.10 | .0853 |
| 8:30 | .46 | .98 | 6.18 | .0842 |
| 9:30 | .45 | .96 | 6.21 | .0822 |
| 10:30 | .46 | .98 | 6.20 | .0832 |
| 11:30 | .45 | .98 | 6.29 | .0843 |
| 12:30 | .45 | .98 | 6.30 | .0842 |
| 1:30 A.M. | .44 | .96 | 6.29 | .0827 |
| 2:30 | .43 | .96 | 6.28 | .0844 |
| 3:30 | .42 | .98 | 6.17 | .0914 |
| 4:30 | .43 | .98 | 6.03 | .0910 |

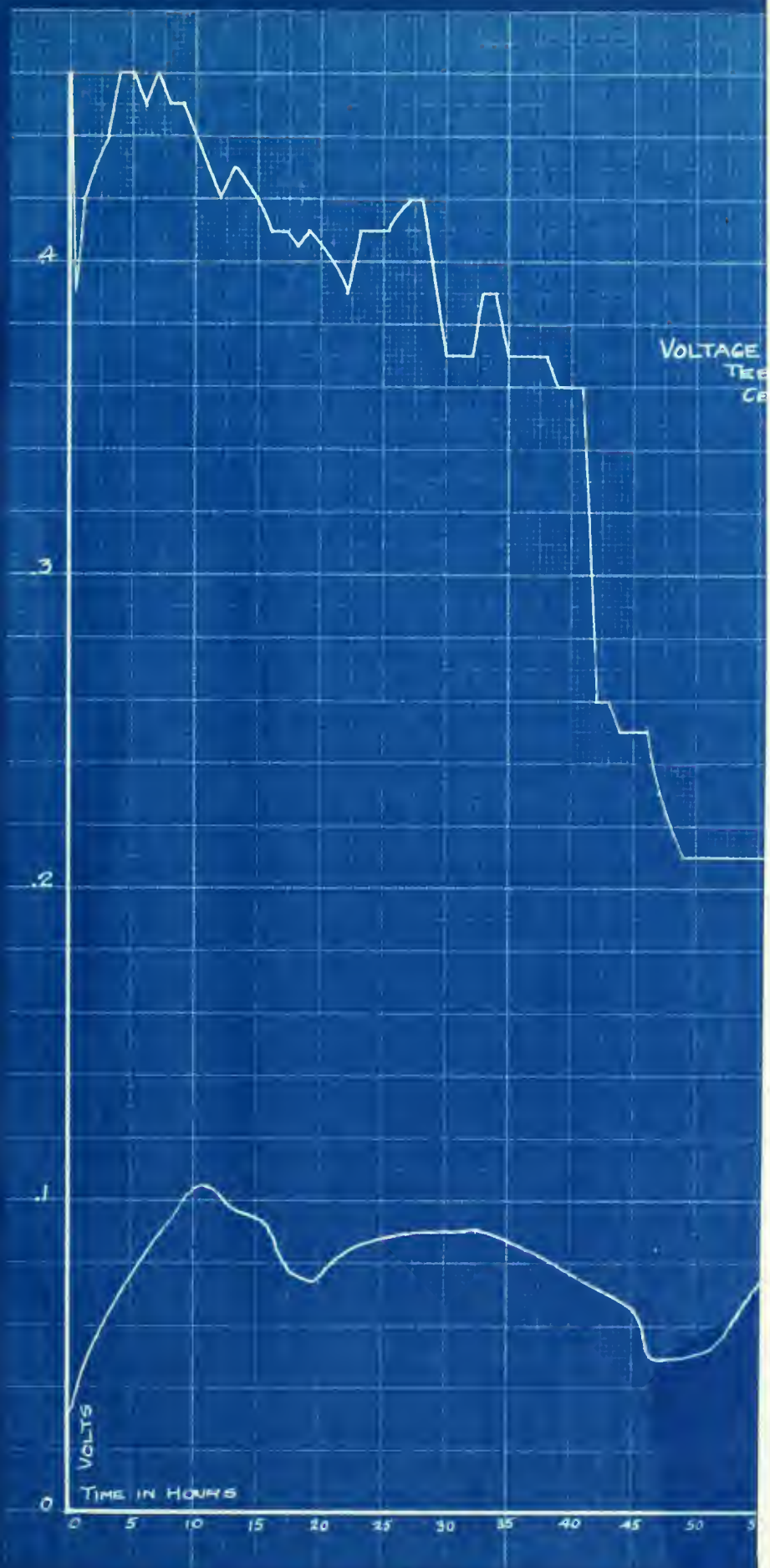
| TIME | $E_c$ | $E_o$ | I | r |
|---|---|---|---|---|
| 5:30 | .425 | .93 | 5.97 | .0846 |
| 6:30 | .42 | .93 | 5.75 | .0888 |
| 7:30 | .41 | .90 | 5.65 | .0867 |
| 8:30 | .41 | .90 | 5.40 | .0907 |
| 9:30 | .405 | .88 | 5.18 | .0932 |
| 10:30 | .41 | .87 | 5.00 | .0920 |
| 11:30 | .405 | .86 | 4.88 | .0916 |
| 12:30 A.M. | .40 | .865 | 4.84 | .0960 |
| 1:30 P.M. | .39 | .86 | 4.82 | .0976 |
| 2:30 | .41 | .89 | 4.74 | .1012 |
| 3:30 | .41 | .87 | 4.67 | .0985 |
| 4:30 | .41 | .88 | 4.60 | .1032 |
| 5:30 | .415 | .88 | 4.55 | .1022 |
| 6:30 | .42 | .89 | 4.55 | .1032 |
| 7:30 P.M. | .42 | .88 | 4.55 | .1011 |
| 8:30 | .40 | .87 | 4.43 | .1058 |
| 9:30 | .37 | .85 | 4.29 | .1118 |
| 10:30 | .37 | .85 | 4.21 | .1140 |
| 11:30 | .37 | .84 | 4.15 | .1132 |
| 12:30 | .39 | .85 | 4.08 | .1125 |

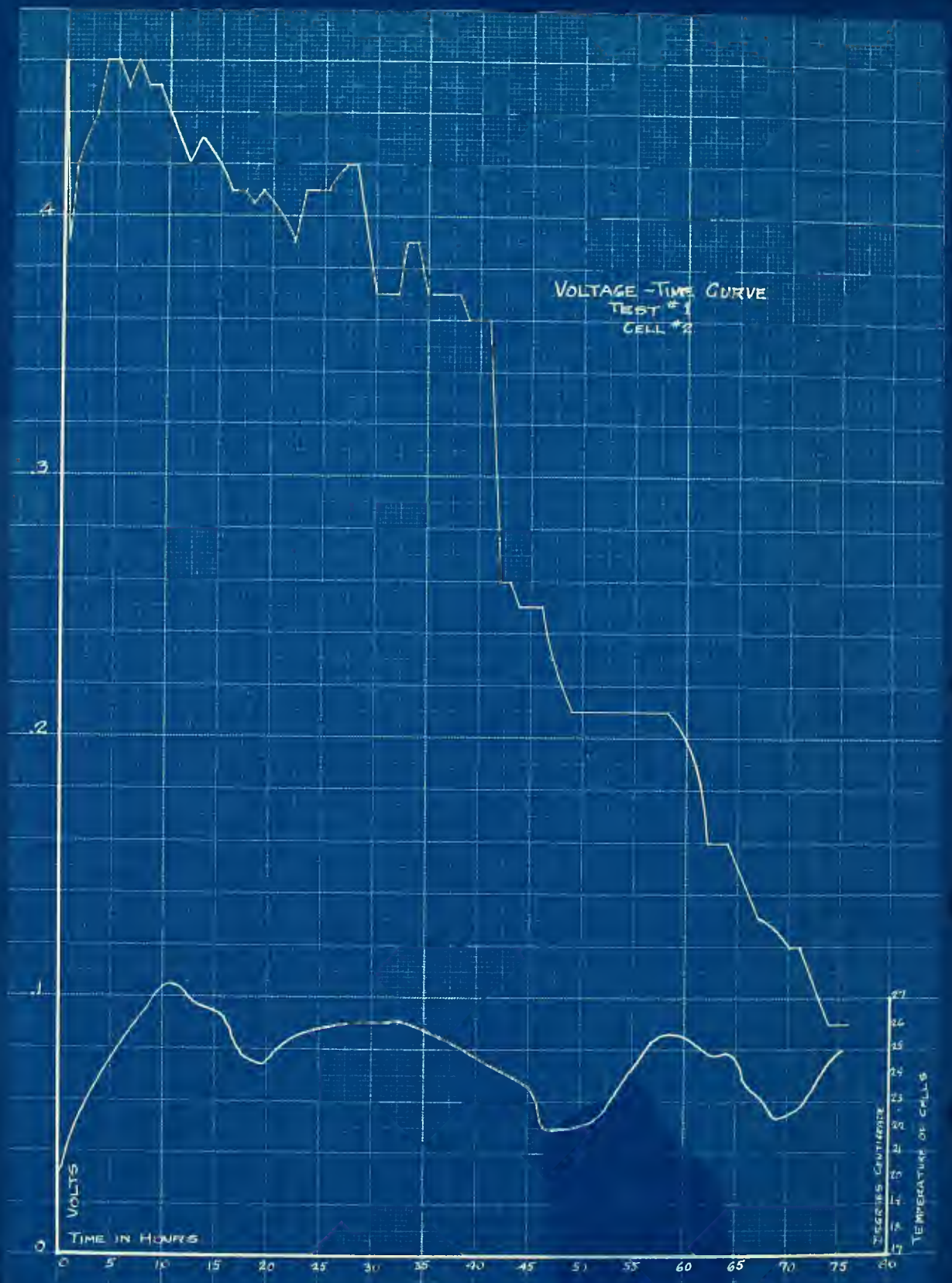
| TIME | $E_c$ | $E_o$ | I | r |
|---|---|---|---|---|
| 1:30 A.M. | .39 | .84 | 4.00 | .1124 |
| 2:30 | .37 | .85 | 3.85 | .1194 |
| 3:30 | .37 | .83 | 3.83 | .1200 |
| 4:30 | .37 | .83 | 3.69 | .1245 |
| 5:30 | .36 | .82 | 3.61 | .1273 |
| 6:30 | .36 | .79 | 3.50 | .1228 |
| 7:30 | .36 | .79 | 3.40 | .1265 |
| 8:30 | .26 | .74 | 3.84 | .1250 |
| 9:30 | .26 | .73 | 3.75 | .1252 |
| 10:30 | .25 | .73 | 3.66 | .1312 |
| 11:30 | .25 | .70 | 3.57 | .1360 |
| 12:30 | .25 | .68 | 3.47 | .1368 |
| 1:30 P.M. | .23 | .68 | 3.32 | .1352 |
| 2:30 | .22 | .67 | 3.26 | .1379 |
| 3:30 | .21 | .66 | 3.19 | .1410 |
| 4:30 | .21 | .66 | 3.16 | .1422 |
| 5:30 | .21 | .655 | 3.10 | .1435 |
| 6:30 | .21 | .65 | 3.09 | .1422 |

| TIME | $E_c$ | $E_o$ | I | r |
|---|---|---|---|---|
| 7:30 | .21 | .62 | 3.07 | .1334 |
| 8:30 | .21 | .61 | 3.07 | .1301 |
| 9:30 | .21 | .64 | 3.07 | .1401 |
| 10:30 | .21 | .66 | 3.09 | .1452 |
| 11:30 | .21 | .66 | 3.06 | .1468 |
| 12:30 P.M. | .21 | .65 | 2.98 | .1476 |
| 1:30 A.M. | .205 | .61 | 2.88 | .1405 |
| 2:30 | .20 | .61 | 2.70 | .1516 |
| 3:30 | .19 | .57 | 2.52 | .1505 |
| 4:30 | .16 | .53 | 2.38 | .1553 |
| 5:30 | .16 | .535 | 2.35 | .1595 |
| 6:30 | .16 | .53 | 2.27 | .1630 |
| 7:30 | .15 | .51 | 2.15 | .1675 |
| 8:30 | .14 | .48 | 1.96 | .1735 |
| 9:30 | .13 | .48 | 1.86 | .1827 |
| 10:30 | .13 | .45 | 1.78 | .1798 |
| 11:30 | .125 | .44 | 1.77 | .1780 |
| 12:30 | .12 | .44 | 1.68 | .1904 |

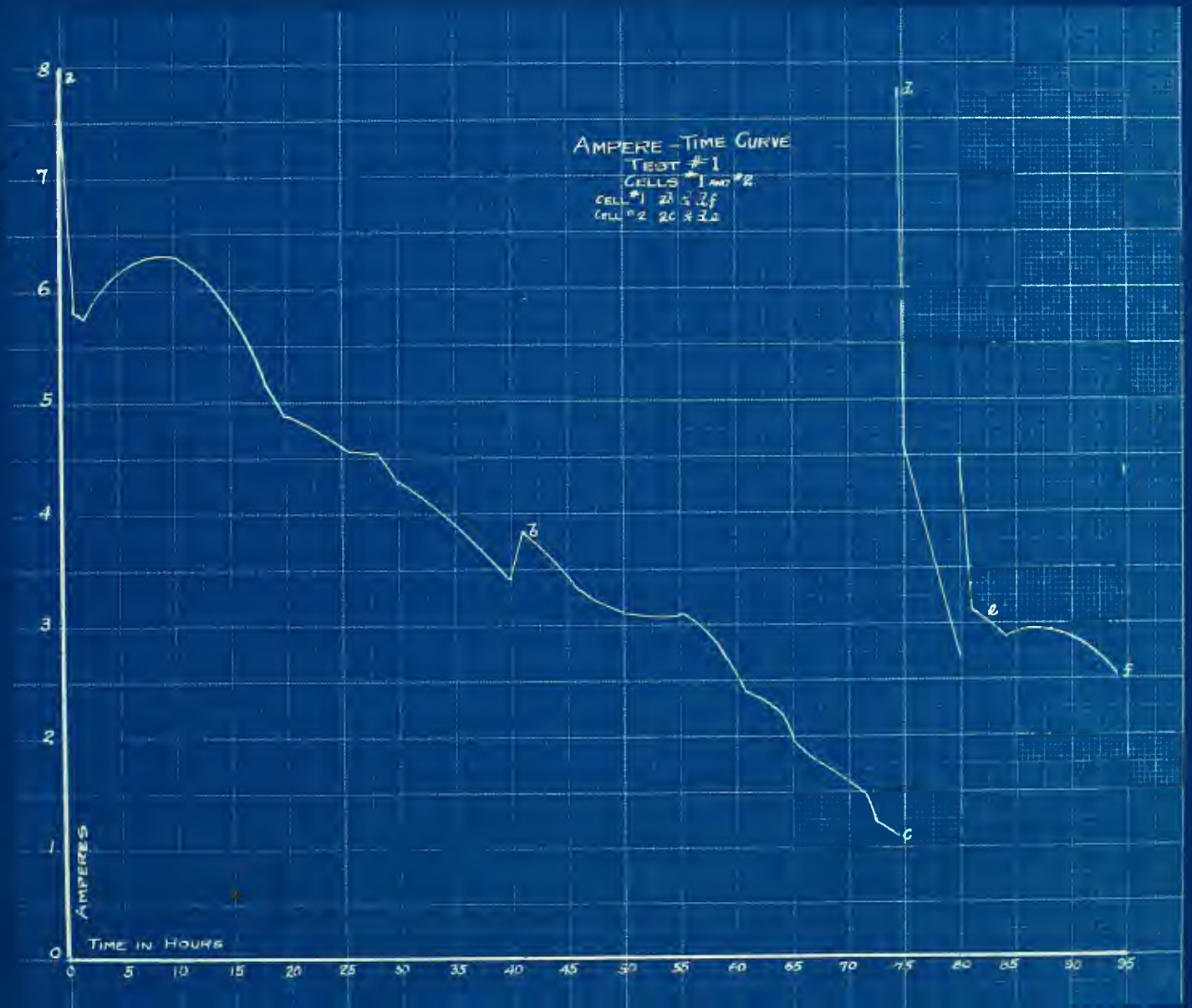
| TIME | $E_c$ | $E_o$ | I | r |
|---|---|---|---|---|
| 1:30 P.M. | .12 | .43 | 1.65 | .1878 |
| 2:30 | .11 | .41 | 1.55 | .1933 |
| 3:30 | .10 | .42 | 1.48 | .2160 |
| 5:30 | .09 | .35 | 1.24 | .2095 |
| 9:30 | .09 | .32 | 1.16 | .1982 |
| 11:30 P.M. | .09 | .33 | 1.11 | .2165 |
| 11:15 A.M. | | | 8.26 | |
| 11:30 | .09 | .75 | 4.60 | .1435 |
| 4:30 P.M. | ---- | 0 | 2.71 | ----- |
| ***** | | | | |
| 10:30 A.M. | .19 | .87 | 4.47 | .1520 |
| 11:30 A.M. | ------ | .52 | 3.12 | ------ |


VOLTAGE - TIME CURVE
TEST #1
CELL #1
VOLTS
TIME IN HOURS
4
3
2
1
0
0
5
10
15
20
25
30
35
40
45
50
55
60
65


.4
.3
.2
.1
0
VOLTS
TIME IN HOURS
0 5 10 15 20 25 30 35 40 45 50
VOLTAGE


VOLTAGE - TIME CURVE
TEST #1
CELL #2
.4
.3
.2
.1
0
VOLTS
TIME IN HOURS
0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80
DEGREES CENTIGRADE
TEMPERATURE OF CELLS

AMPERE - TIME CURVE
TEST # 1
CELLS #1 AND #2
CELL #1 2b & 2f
CELL #2 2c & 2a
8
7
6
5
4
3
1
2
3


AMPERE-TIME CURVE
TEST #1
CELLS #1 AND #2
CELL #1 2B = 2.f
CELL #2 2C = 2.2
a
b
c
d
e
f
AMPERES
TIME IN HOURS
0
1
2
3
4
5
6
7
8
0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95

Part # II.

Test #2

One cell in circuit--Lower Discharge Rate

## Test #2

In the second test the better of the two cells used in the first test was chosen to be tested at a lower current output rate, namely cell #2.

In this test the density of the cup and the outer solutions was increased to 15° Baume, the object being in addition to replacing the water left over by the previous charge in the cup to raise the voltage to what it normally should be on open circuit. The cell's voltage on open circuit then became 1.92 volts.

The resistance was adjusted so that the current after the first throw of the needle to 2.52 amperes, decreased and became constant at 2.1 amperes.

The quantities on the data sheets for this test have the same meaning as was given them in Test #1.

As in Test #1 curves were plotted

showing the variation of volts, amperes and temperature of the cell with time in hours. As before the curves were plotted point to point. The area of the ampere-time curve was very carefully measured with a planimeter, an area which, when reduced to the scale of the coordinates, represents the ampere-hour output of the cell.

Calculations and results:

Cell #2

Wt. of Zn. + Hg. before test = 2924.359 grams

Wt. of Zn. + Hg. after test = 2258.928

total loss in zinc = 665.431 grams

Area of amp.-hr. curve = 274.55 sq.cm.

1sq.cm. = .2x10 = 2 amp.-hrs.

area = 2 x 274.55 = 549.10 amp.-hrs.

Calculated loss:

Amp.-hrs. output of cell = 549.10 amp.-hrs.

loss = 549.10 x 3600 x .000336 = 664.411 gr.

So that the loss due to local action is

665.431 grams - 664.411 grams = 1.020 grams

Thus giving an efficiency of $\frac{665.431}{664.411} \times 100 =$

99.5%

The average voltage of the cell as determined from the voltage-time curve is .61 volts, so that the watt-hours output of the cell is 329.46 watt-hrs. and since the cell weighed 35.904 #, the output per pound is 9.18 watt-hours, and the output per cubic foot of space occupied is 367. watt-hours.

Cost of materials:

Wt. of outer sol. = 13.7#

Wt. of cup sol. = +1.38

total wt. of sols.= 15.08 #

Since density of acid = 15° Baume = 1.109 sp. gr., wt. of actual acid = $\frac{15.08}{69.151} \times 6.796 = 1.48$ #

This amount of acid will make 3.09 # of commercial acid, which will cost 3.09 cents.

1.285 # $KClO_3$ used costs 12.16 cents

Zinc used = 1.467 # and costs 12.49 cents

Total cost of materials for 329.46 watt-hours is $0.285 at which rate the cost of materials per K.W.H. is $0.865

DATA on Test #2.

Cell #2.

Started 4/13/11.

| Time | $E_c$ | $E_o$ | I | r |
|---|---|---|---|---|
| 10:30 P.M. | 1.57 | | 2.52 | |
| 11:00 | 1.15 | 1.4 | 2.10 | .1190 |
| 11:30 | 1.17 | 1.4 | 2.07 | .1112 |
| 12:30 | 1.14 | 1.4 | 2.06 | .1261 |
| 1:30 A.M. | 1.13 | 1.37 | 2.05 | .1172 |
| 2:30 | 1.10 | 1.35 | 2.01 | .1244 |
| 3:30 | 1.08 | 1.35 | 1.98 | .1362 |
| 4:30 | 1.06 | 1.37 | 1.95 | .1590 |
| 6:00 | 1.05 | 1.31 | 1.93 | .1347 |
| 7:00 | 1.03 | 1.28 | 1.89 | .1322 |
| 9:30 | 1.00 | 1.20 | 1.81 | .1104 |
| 11:30 | .95 | 1.17 | 1.75 | .1258 |
| 1:30 P.M. | .93 | 1.145 | 1.71 | .1258 |
| 3:30 | .92 | 1.13 | 1.69 | .1242 |
| 5:30 | .91 | 1.12 | 1.66 | .1265 |

| Time | $E_c$ | $E_o$ | I | r |
|---|---|---|---|---|
| 7:00 | .90 | 1.11 | 1.65 | .1273 |
| 9:30 | .89 | 1.11 | 1.63 | .1350 |
| 11:30 | .88 | 1.11 | 1.62 | .1418 |
| 1:30 A.M. | .88 | 1.11 | 1.61 | .1428 |
| 3:30 | .88 | 1.10 | 1.69 | .1301 |
| 7:30 | .86 | 1.07 | 1.57 | .1338 |
| 9:30 | .80 | 1.07 | 1.57 | .1720 |
| 11:30 | .84 | 1.06 | 1.56 | .1411 |
| 1:30 P.M. | .82 | 1.05 | 1.54 | .1492 |
| 3:30 | .81 | 1.05 | 1.52 | .1580 |
| 5:30 | .81 | 1.04 | 1.51 | .1522 |
| 7:30 | .81 | 1.04 | 1.50 | .1532 |
| 9:30 | .81 | 1.035 | 1.50 | .1500 |
| 11:30 | .81 | 1.04 | 1.50 | .1532 |
| 1:30 A.M. | .805 | 1.03 | 1.49 | .1510 |
| 3:30 | .80 | 1!015 | 1.48 | .1452 |
| 10:00 | .80 | 1.02 | 1.475 | .1488 |
| 11:00 | .79 | 1.015 | 1.47 | .1530 |

| Time | $E_c$ | $E_o$ | I | r |
|---|---|---|---|---|
| 1:00 P.M. | .78 | 1.01 | 1.44 | .1596 |
| 3:00 | .77 | 1.00 | 1.44 | .1597 |
| 5:00 | 1.04 | 1.38 | 1.90 | .1790 |
| 7:00 | .79 | 1.015 | 1.46 | .1540 |
| 9:00 | .76 | 1.01 | 1.41 | .1772 |
| 11:00 | .755 | 1.00 | 1.40 | .1750 |
| 4:00 A.M. | .76 | .975 | 1.405 | .1530 |
| 7:00 | .755 | .96 | 1.40 | .1534 |
| 10:00 | .76 | .975 | 1.42 | .1512 |
| 1:00 P.M. | .76 | 1.01 | 1.43 | .1747 |
| 4:00 | .755 | 1.01 | 1.41 | .1807 |
| 7:00 | .76 | .975 | 1.40 | .1535 |
| 10:00 | .76 | .975 | 1.40 | .1535 |
| 1:00 A.M. | .76 | .975 | 1.40 | .1535 |
| 4:00 | .76 | .975 | 1.40 | .1535 |
| 7:00 | .76 | .975 | 1.40 | .1535 |
| 10:00 | .76 | .975 | 1.40 | .1535 |
| 1:00 P.M. | .775 | 1.00 | 1.43 | .1572 |

| Time | $E_c$ | $E_o$ | I | r |
|---|---|---|---|---|
| 4:00 | .80 | 1.02 | 1.455 | .1511 |
| 7:00 | .79 | 1.015 | 1.47 | .1530 |
| 10:00 | .79 | 1.015 | 1.46 | .1540 |
| 1:00 A.M. | .80 | 1.03 | 1.46 | .1575 |
| 4:00 | .80 | 1.04 | 1.48 | .1682 |
| 7:00 | .815 | 1.03 | 1.48 | .1452 |
| 10:00 | .79 | 1.01 | 1.45 | .1516 |
| 1:00 P.M. | .78 | 1.01 | 1.44 | .1596 |
| 4:00 | .79 | 1.00 | 1.455 | .1443 |
| 7:00 | .80 | 1.03 | 1.48 | .1556 |
| 10:00 | .80 | 1.03 | 1.46 | .1575 |
| 1:00 A.M. | .80 | 1.02 | 1.45 | .1517 |
| 3:00 | .80 | 1.03 | 1.44 | .1596 |
| 7:30 | .80 | 1.02 | 1.45 | .1518 |
| 10:00 | .79 | 1.02 | 1.46 | .1576 |
| 1:00 P.M. | .80 | 1.02 | 1.46 | .1505 |
| 4:00 | .78 | 1.02 | 1.45 | .1656 |
| 7:00 | .77 | 1.015 | 1.43 | .1712 |

| Time | $E_c$ | $E_o$ | I | r |
|---|---|---|---|---|
| 10:00 | .765 | 1.01 | 1.40 | .1750 |
| 1:00 A.M. | .75 | 1.00 | 1.38 | .1810 |
| 4:00 | .75 | .98 | 1.37 | .1678 |
| 8:00 | .75 | .975 | 1.38 | .1630 |
| 10:00 | .75 | .975 | 1.38 | .1630 |
| 1:00 P.M. | .75 | .975 | 1.38 | .1630 |
| 4:00 | .745 | .975 | 1.36 | .1690 |
| 7:00 | .72 | .96 | 1.33 | .1802 |
| 10:00 | .70 | .93 | 1.28 | .1798 |
| 12:00 | .69 | .92 | 1.26 | .1825 |
| 2:00 A.M. | .67 | .90 | 1.22 | .1885 |
| 6:00 | .66 | .88 | 1.13 | .1945 |
| 10:00 | .69 | .905 | 1.17 | .1837 |
| 12:00 | .71 | .94 | 1.22 | .1885 |
| 2:00 P.M. | .71 | .94 | 1.23 | .1870 |
| 4:00 | .72 | .955 | 1.25 | .1880 |
| 6:00 | .73 | .965 | 1.28 | .1835 |
| 8:00 | .73 | .965 | 1.279 | .1855 |

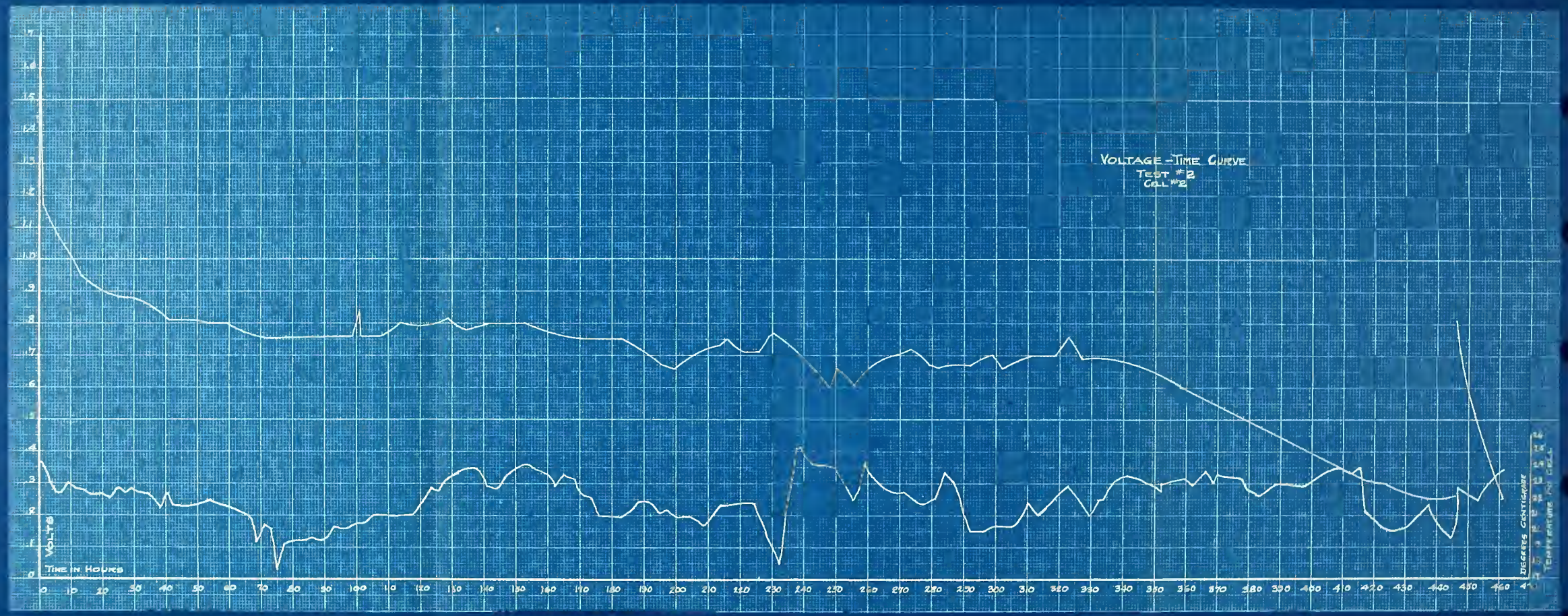
| Time | $E_c$ | $E_o$ | I | r |
|---|---|---|---|---|
| 10:30 P.M. | .75 | .96 | 1.20 | .1750 |
| 12:00 | .73 | .95 | 1.27 | .1732 |
| 2:00 A.M. | .72 | .95 | 1.25 | .1838 |
| 4:00 | .71 | .78 | 1.19 | ------ |
| 6:00 | .78 | 1.015 | 1.29 | .1820 |
| 8:00 | .71 | .78 | 1.31 | ------ |
| 11:30 | .76 | 1.01 | 1.30 | .1921 |
| 1:00 P.M. | .755 | 1.01 | 1:30 | .1962 |
| 2:30 | .77 | 1.01 | 1.29 | .1860 |
| 4:00 | .74 | 1.00 | 1.29 | .2014 |
| 6:00 | .73 | .96 | 1.26 | .1824 |
| 8:00 | .72 | .955 | 1.20 | .1955 |
| 10:00 | .70 | .93 | 1.195 | .1926 |
| 12:00 | .68 | .905 | 1.18 | .1908 |
| 5:00 A.M. | .62 | .84 | 1.09 | .2015 |
| 7:00 | .60 | .82 | 1.07 | .2055 |
| 9:00 | .60 | .81 | 1.08 | .1945 |
| 11:00 | .66 | .81 | 1.17 | .1795 |
| 3:00 P.M. | .62 | .84 | 1.09 | .1015 |
| 5:00 | .61 | .82 | 1.00 | .2100 |

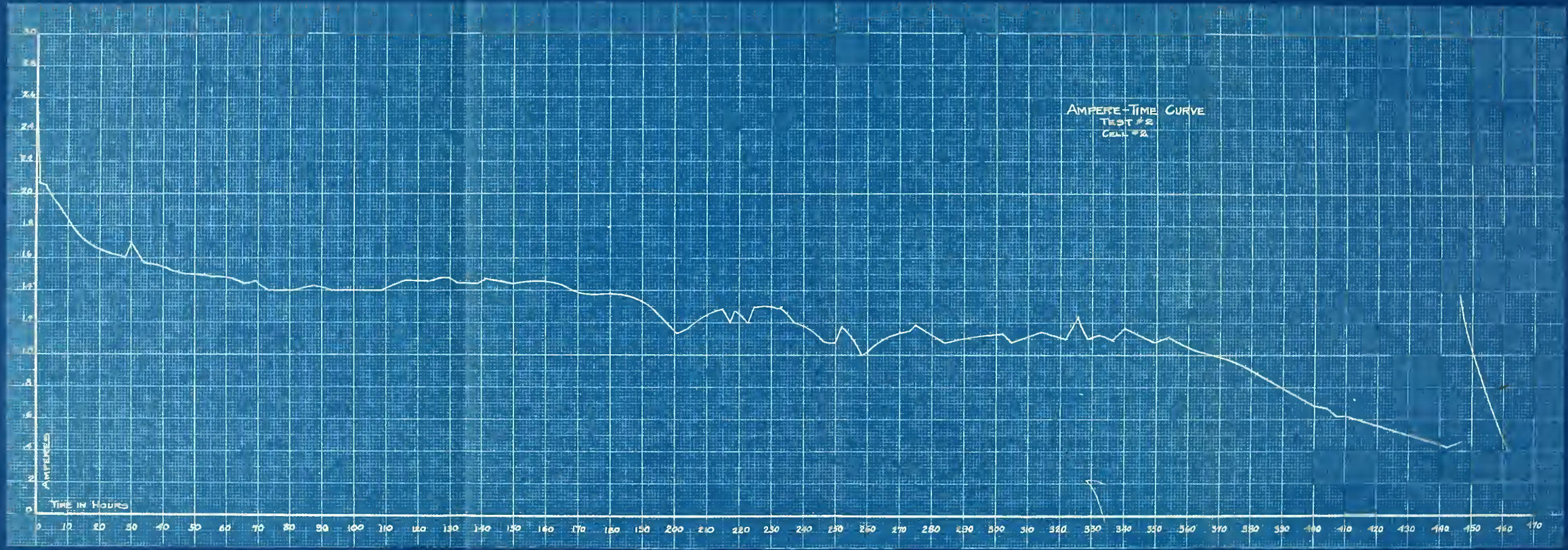
| Time | $E_c$ | $E_o$ | I | r |
|---|---|---|---|---|
| 7:00 | .65 | .87 | 1.05 | .2092 |
| 10:00 | .67 | .91 | 1.09 | .2200 |
| 12:00 | .69 | .92 | 1.10 | .2090 |
| 5:00 A.M. | .70 | .92 | 1.14 | .1930 |
| 8:00 | .71 | .93 | 1.15 | .1915 |
| 10:00 | .72 | .95 | 1.18 | .1949 |
| 1:00 P.M. | .705 | .95 | 1.16 | .2110 |
| 4:00 | .67 | .905 | 1.10 | .2150 |
| 7:00 | .66 | .90 | 1.08 | .2225 |
| 10:00 | .67 | .905 | 1.09 | .2155 |
| 5:00 A.M. | .66 | .90 | 1.09 | .2200 |
| 8:00 | .69 | .92 | 1.13 | .2034 |
| 10:00 | .70 | .92 | 1.13 | .1946 |
| 1:00 P.M. | .70 | .93 | 1.13 | .2032 |
| 4:00 | .66 | .92 | 1.08 | .2408 |
| 7:00 | .68 | .92 | 1.10 | .2180 |
| 10:00 | .68 | .90 | 1.10 | .2000 |
| 1:00 A.M. | .70 | .945 | 1.14 | .2150 |
| 8:30 | .70 | .93 | 1.10 | .2092 |

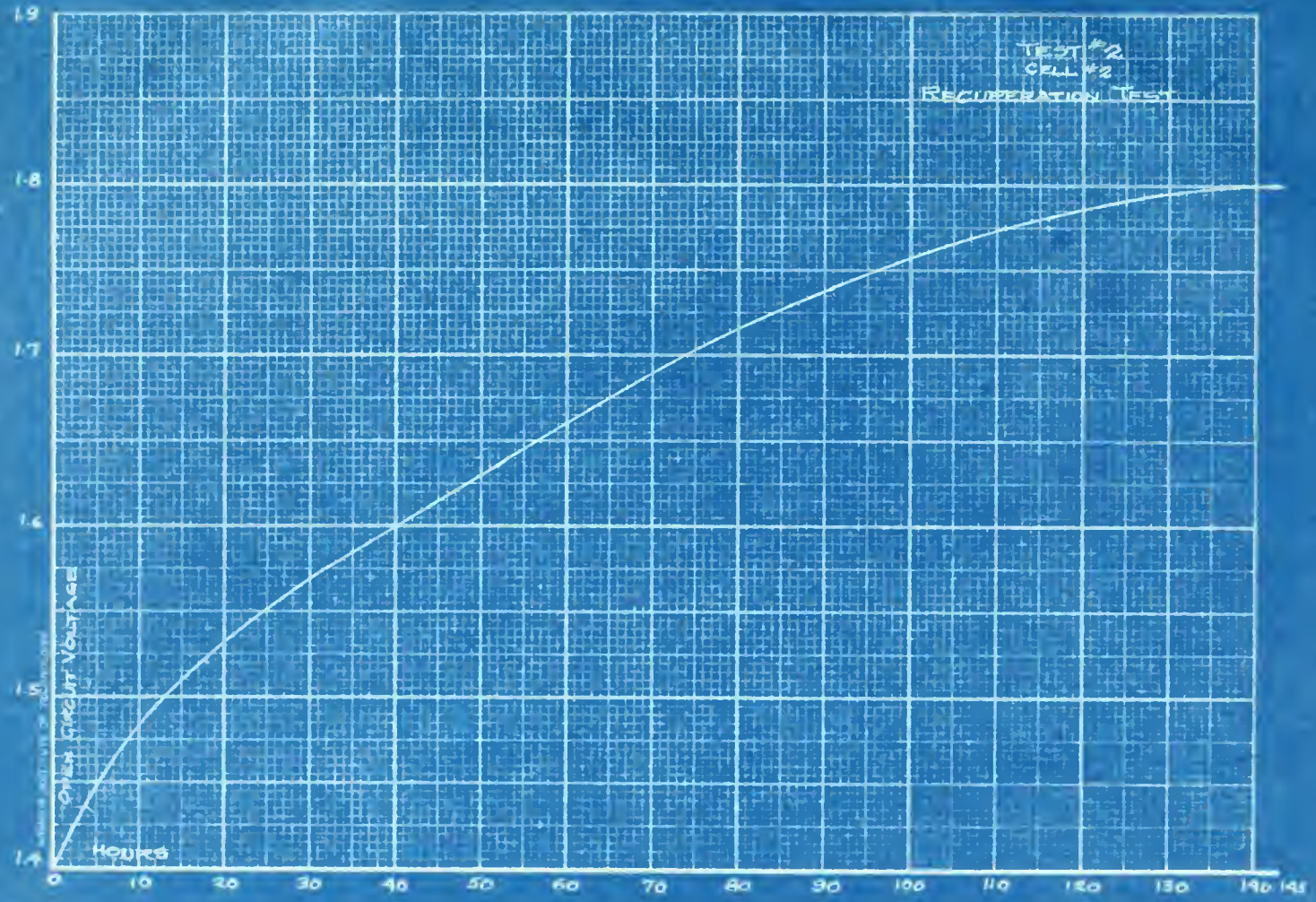
| Time | $E_c$ | $E_o$ | I | r |
|---|---|---|---|---|
| 12.30 A.M. | .755 | 1.03 | 1.34 | .2220 |
| 1:00 P.M. | .74 | 1.02 | 1.18 | .2370 |
| 4:00 | .69 | .93 | 1.10 | .2451 |
| 7:00 | .70 | .94 | 1.13 | .2124 |
| 11:00 | .69 | .93 | 1.10 | .2182 |
| 2:00 A.M. | .69 | .93 | 1.17 | .2050 |
| 8:30 | .66 | .90 | 1.09 | .2222 |
| 11:30 | .655 | .90 | 1.08 | .2270 |
| 3:30 P.M. | .62 | .88 | 1.11 | .2342 |
| 7:00 | .595 | .84 | 1.08 | .2270 |
| 10:00 | .61 | .84 | 1.05 | .2190 |
| 12:00 | .57 | .82 | 1.03 | .2425 |
| 8:00 A.M. | .56 | .80 | .99 | .2429 |
| 10:00 | .55 | .79 | .98 | .2450 |
| 12:00 | .54 | .78 | .96 | .2500 |
| 2:00 P.M. | .54 | .76 | .95 | .2312 |
| 4:00 | .52 | .75 | .94 | .2445 |

| Time | $E_c$ | $E_o$ | I | r |
|---|---|---|---|---|
| 6:00 | .51 | .74 | .90 | .2553 |
| 8:00 P.M. | .50 | .93 | .89 | .4830 |
| 10:00 | .486 | .92 | .85 | .5120 |
| 12:00 | .48 | .90 | .84 | .5000 |
| 5:00 A.M. | .44 | .66 | .78 | .2820 |
| 10:00 | .42 | .61 | .72 | .2635 |
| 12:00 | .39 | .59 | .70 | .2855 |
| 2:00 P.M. | .38 | .59 | .68 | .3090 |
| 4:00 | .38 | .58 | .68 | .2940 |
| 6:00 | .375 | .57 | .67 | .2910 |
| 9:00 | .37 | .56 | .62 | .3310 |
| 2:00 A.M. | .34 | .54 | .60 | .3330 |
| 4:00 | .34 | .54 | .60 | .3330 |
| 9:00 | .31 | .51 | .56 | .3570 |
| 11:00 | .31 | .51 | .56 | .3570 |
| 1:00 P.M. | .305 | .50 | .53 | .3675 |
| 3:00 | .30 | .48 | .51 | .3530 |
| 5:00 | .28 | .43 | .51 | .3920 |

| Time | $E_c$ | $E_o$ | I | r |
|---|---|---|---|---|
| 7:00 | .28 | .47 | .50 | .3800 |
| 9:00 | .26 | .46 | .49 | .4080 |
| 11:00 | .26 | .44 | .47 | .3830 |
| 1:00 A.M. | .255 | .435 | .46 | .3912 |
| 6:00 | .25 | .41 | .42 | .3810 |
| 10:00 | .255 | .43 | .44 | .3980 |
| 12:00 | .26 | .43 | .46 | .3700 |
| ******** | | | | |
| 11:45 P.M. | .81 | 1.12 | 1.37 | .2264 |
| 12:00 | .76 | 1.08 | 1.31 | .2442 |
| 1:30 A.M. | .71 | 1.00 | 1.20 | .2441 |
| 6:00 | .52 | .75 | .87 | .2645 |
| 11:00 | .37 | .54 | .61 | .2790 |
| 12:30 | .32 | .47 | .51 | .2941 |
| 3:00 P.M. | .25 | .40 | .39 | .3850 |


VOLTAGE-TIME CURVE
TEST #2
CELL #2
VOLTS
TIME IN HOURS
DEGREES CENTIGRADE
TEMPERATURE OF CELL


AMPERE-TIME CURVE
TEST #2
CELL #2
AMPERES
TIME IN HOURS


TEST #2
CELL #2
RECUPERATION TEST
OPEN CIRCUIT VOLTAGE
HOURS
1.9
1.8
1.7
1.6
1.5
1.4
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
145

# Part III.

## Summation and Discussion of Results

## Summation and Discussion of Results

The voltage which the makers claim for the cell on open circuit was not obtained with solutions having a density of 11.5° Baume, cell #1 in the first test having the highest voltage obtainable, namely 1.425 volts. Increasing the density of the acid to 15° raised the voltage of #2 to 1.92 volts. It is probable that a still further increase in the density would have again raised the open circuit voltage.

Referring to the voltage-time curves it will be noted that cell #2 is much the better cell. In test #1 the voltages of both cells are plotted to the same scales. In this test the difference is very noticeable. The closed circuit voltage of the cell #2 displays a very close regulation, a maximum variation of only 13.3% from the average value for the first forty hours of the test at which time cell #1

is exhausted. Remembering that the cell is giving out a comparatively enormous continuous current, the regulation of this cell is remarkable.

In test #2 the ampere-hours output of cell #2 has been greatly increased thus indicating that the cell will give a greater useful output on a low continuous discharge rate than on a high rate.

It costs more per K.W.H. to operate the cell at a high rate of discharge than at a low rate. This is shown very nicely by the "cost of materials" calculations for each test. The calculations in both tests were based upon the materials used in cell #2. By reference to the calculations it will be seen that the cost of materials actually used by the cell per K.W.H. based on the assumption noted is $1.53. This cost is high enough to preclude its original instablation as a power battery

in as much as other cells made by The Battery Company are designed especially for power work and in which the cost of renewals per K. W.H. is considerably less than the amount above mentioned. With the lower current output rate as shown under test #2 this cost per K.W.H. decreases to $0.866. From these figures it seems that the behaviour of this cell would be very nearly ideal when used in signal circuits where the constant current discharge rate would not exceed say .2 ampere. Under test #3 the high zinc efficiency indicates that there is very little local action in the cell.

When the cell is in actual operation, chlorine gas from the depolarizer is given off but the quantities of this gas even at a high current output are not large enough to be very UNPLEASANT

When the cells were set up for the first time the zincs were marked lightly with a lead pencil "#1" and "#2" respectivly. At the con-

clusion of a preliminary test, which is not recorded, the symbols "½"1" and "½"2", were found to be etched into the zinc due to a small local cell being formed between the zinc and graphite from the lead pencil - a suggestion which might be used for etching other metals. It is understood that someone at the Battery Company is, as the result of this observation, experimenting with regard to its utility in etching steel.